EXOTIC PLANTS AT THE DESERT LABORATORY, TUCSON, ARIZONA

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ABSTRACT

A census and mapping of the exotic flora of the Desert Laboratory grounds, Tucson, Arizona, is described. Most of the 52 exotic species are restricted to disturbed habitats. Five annuals (*Bromus rubens, Erodium cicutarium, Hordeum murinum, Sisymbrium irio,* and *Schismus* sp.) and one perennial grass (*Pennisetum ciliare*) have invaded extensive areas of undisturbed Sonoran Desert vegetation. Shared features of these six species are discussed with respect to climates of origin, evolution with pastoralism, grazing history of southern Arizona, integration into native food webs, and reproductive biology. The invasions appear to be irreversible, and other exotic species show signs of becoming increasingly invasive. What has occurred on the Desert Laboratory grounds may represent the future pattern for much of the eastern Sonoran Desert. The present status and history of introduction of each exotic species are presented in an appendix.

In 1903 the Carnegie Institute of Washington established the Desert Laboratory at Tucson, Arizona, to investigate desert plant ecology (Coville et al. 1903). Soon afterwards, Spalding (1909) mapped the distribution of two exotic plant species, *Erodium cicutarium* and *Hordeum murinum,* on the Desert Laboratory grounds. *Cynodon dactylon* was the only other exotic in the Desert Laboratory flora (Spalding 1909). Since then, exotic species have proliferated, and the total is now 52 (Bowers and Turner 1985; Turner and Bowers 1988).

Much research on exotic plants in the North American deserts has concentrated on disturbed habitats. In the Great Basin, Eurasian annuals such as *Salsola australis, Bromus tectorum* L., *Sisymbrium altissimum* L., and *Descurainia sophia* (L.) Webb. naturalized in sagebrush scrub following intensive burning and grazing (Piemeisel 1951; Young et al. 1972; Yensen 1981; Mack 1981, 1986). In the Sonoran Desert, *Salsola australis, Schismus* spp., *Sisymbrium irio, Bromus rubens* and *Erodium cicutarium* colonized abandoned farmland (Karpiscak 1980). *Erodium cicutarium* and *Bromus rubens* established on land that had been denuded of vegetation but not plowed in the Mojave Desert (Piemeisel 1932) as well as on other disturbed sites (Rickard and Sauer 1982). Less attention has been paid to establishment of exotics in undisturbed desert communities. Beatley's (1966) study of *Bromus* species in the Mojave Desert is a notable exception. The goal of the present study was to document the status

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and history of exotic plants at the Desert Laboratory, particularly those naturalized in undisturbed habitats.

Study Area

The Desert Laboratory grounds include Tumamoc Hill and the level to gently rolling plain to the west, 352 ha in all (Fig. 1). A rocky outlier of the Tucson Mountains, the hill rises 245 m above the surrounding plain to an elevation of 948 m and is composed of Tertiary volcanics. Adjacent lower areas contain alluvial deposits of varying ages and outcrops of Cretaceous clay.

The climate features mild winters, hot summers and biseasonal precipitation. Afternoon temperatures from June through September often exceed 38°C. Minimum temperatures on the hill may remain above freezing in a mild winter or drop as low as −8.9°C in the coldest ones. In the rather severe winter of 1931–1932, there were 18 freezing nights on the hill (Turnage and Hinckley 1938). Yearly rainfall from 1904 to 1980 averaged about 250 mm/year. About half of the yearly total comes during July, August and September. Most of the remainder falls between October and April.

Study-area vegetation is typical of the Arizona Upland Subdivision of the Sonoran Desert (Shreve 1951). Dominants include *Cercidium microphyllum* (Torr.) Rose & I. M. Johnst., *Larrea tridentata* (DC.) Cov., *Opuntia versicolor* Engelm., *O. phaeacantha* Engelm., *Fouquieria splendens* Engelm., *Lycium berlandieri* Dun., *Encelia farinosa* Gray, and *Ambrosia deltoidea* (Torr.) Payne. Along the washes *Cercidium floridum* Benth., *Prosopis velutina* Woot., *Acacia constricta* Benth., and *A. greggii* Gray are common. Spalding (1909) and Goldberg and Turner (1986) provide more detailed descriptions.

Grazing on the Desert Laboratory grounds ceased when the property was fenced in 1907. Before then, cattle and goats fed "in considerable numbers" on Tumamoc Hill (Bowers 1989). Grazing was severe enough that after four years of protection, Thornber detected "a marked increase in the perennial grasses," notably *Hilaria mutica* (Buckl.) Benth., *Hilaria belangeri* (Steud.) Nash, *Bouteloua curtipendula* (Michx.) Torr., and *Muhlenbergia porteri* Scribn. (Thornber 1910, p. 292). After fencing, the grounds were little disturbed until the 1950's, when easements were granted for three gas pipelines and three electric powerlines. Other localized disturbances in the past three decades have included a sanitary landfill and a clay quarry (both now abandoned) and several roads.

Despite these local alterations, the Desert Laboratory grounds, situated 5 km west of downtown Tucson, have been stable relative to their environs. In 1910 Tucson's population was 13,913 and its urban area was 3.1 km^2 (Bufkin 1981). North and east of the Desert Laboratory were cultivated fields; south and west lay undeveloped

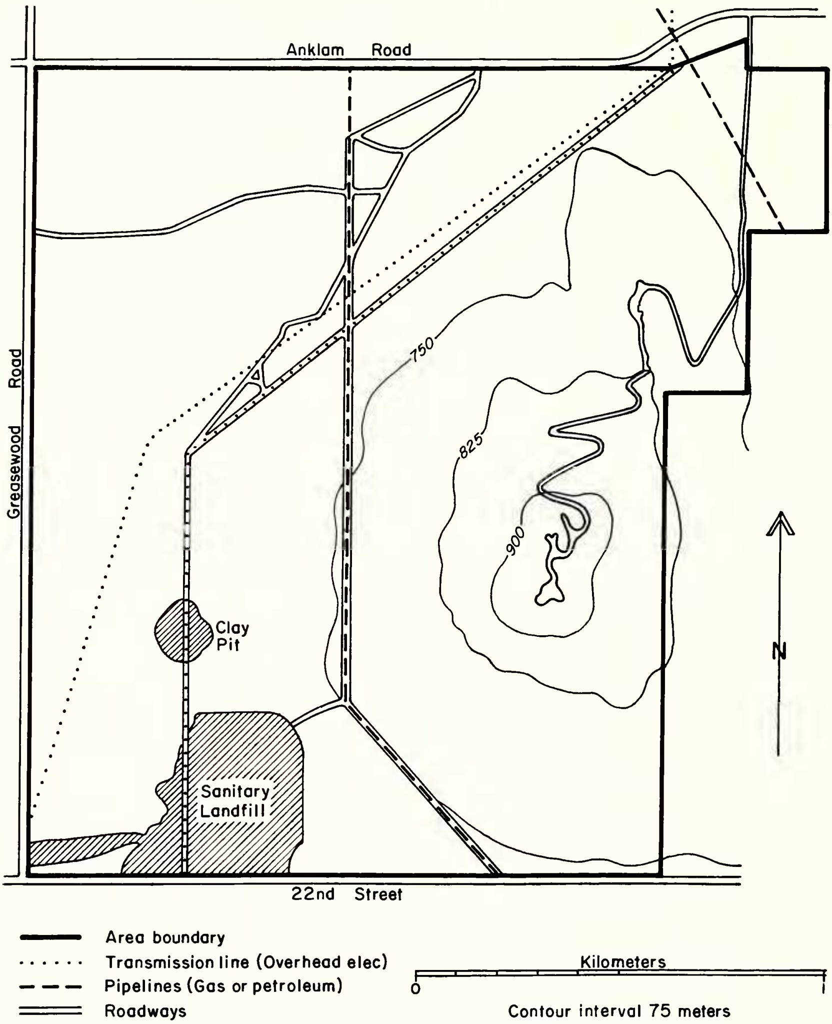

FIG. 1. Map of Desert Laboratory showing boundaries, paved road, outline of landfill and washes.

desert. By 1980 Tucson's urbanized area held approximately 500,000 people in 324 km^2, and the Desert Laboratory grounds were almost surrounded by suburban developments.

SURVEY FOR EXOTIC PLANTS

We surveyed the Desert Laboratory grounds for exotic plants from February to June of 1983. We marked gridlines on aerial photographs (scale 1:2256) of the property, then, using the photographs as a guide, we walked each gridline, remaining on it insofar as possible. The gridlines were 226 m apart and had a total length of about 40 km. We recorded the Cartesian coordinates and relative abundance of all exotic plants encountered within about 2 m of the lines. We also surveyed the paved road (Fig. 1) and all other disturbed or artificial habitats not intersected by the grid. Using the coordinates, we generated a distribution map for each species encountered. In the course of this survey we found 33 of the 52 exotics in the flora (Appendix 1). The remainder are so infrequent that our survey grid did not intersect them.

Results and Discussion

Localized exotics. A few of the exotics recorded during our survey are restricted to particular, usually artificial, habitats. These include such species as *Phalaris minor* and *Polypogon monspeliensis,* known from ephemeral ponds at the landfill, and *Salsola australis,* abundant on dry, disturbed landfill substrates. *Salsola* seeds cannot germinate once the soil has formed a crust; thus the species is most characteristic of recently disturbed sites (Karpiscak 1980).

Many more exotics, while local in distribution, can be identified with no particular habitat. Some apparently require soil disturbance. *Matthiola longipetala* is occasional on the landfill and nearby roadsides, whence it is spreading to disturbed habitats nearby. Others seem not to need disturbed seedbeds and may eventually spread extensively. In the 30 years since *Brassica tournefortii* first appeared near Yuma, Arizona (Mason 1960), it has established along roads and in undisturbed desert in western Arizona. On the Desert Laboratory grounds, this species is especially abundant along the western boundary fenceline whence it is colonizing the grounds using washes as corridors. *Dimorphotheca sinuata,* an ornamental annual commonly cultivated in Tucson, is invading from the southwest edge of the property, where it has doubtless escaped from cultivation in a nearby housing development. Like *Brassica, Dimorphotheca* spreads along washes.

The process of introduction continues. Two exotics appeared on the grounds after the 1983 survey—*Caesalpinia gilliesii* and *Opuntia microdasys.* Both are common ornamentals in nearby yards and gardens.

Naturalized exotics. Five exotic annuals and one exotic perennial have naturalized on our study area; that is, they self-seed in undisturbed habitats and occur as frequently as common native species. *Erodium cicutarium* and *Hordeum murinum* occupied scattered patches on the northwest side of the Tumamoc Hill property in 1906 (SapldING 1909). Both have since naturalized throughout the grounds

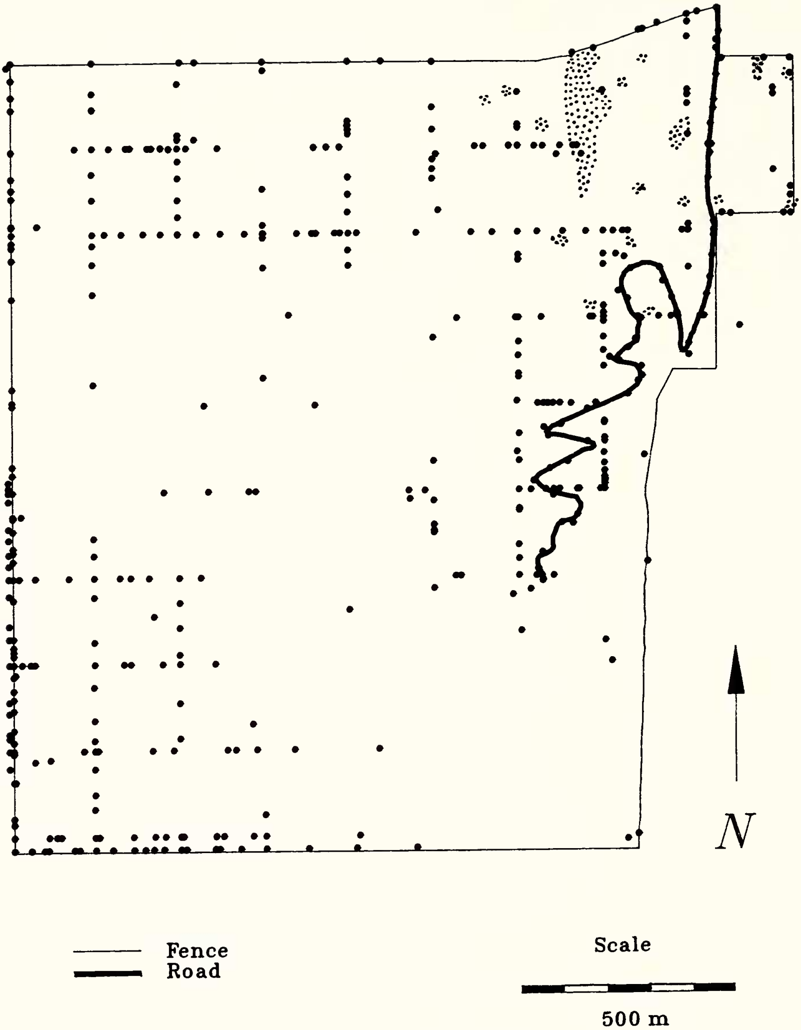

FIG. 2. Distribution of *Erodium cicutarium* at Desert Laboratory in 1906 (stippled areas) and 1983 (dots). From Turner and Bowers (1988).

(Figs. 2, 3). *Sisymbrium irio, Bromus rubens,* and *Schismus* spp. have also naturalized on our study area, apparently within the last 50 to 76 years (Appendix 1). *Pennisetum ciliare,* a perennial grass, forms colonies up to 20 m across on rocky slopes of Tumamoc Hill and is also common along some washes. It has spread steadily since our 1983 survey and, like the six exotic annuals, establishes well in undisturbed habitats.

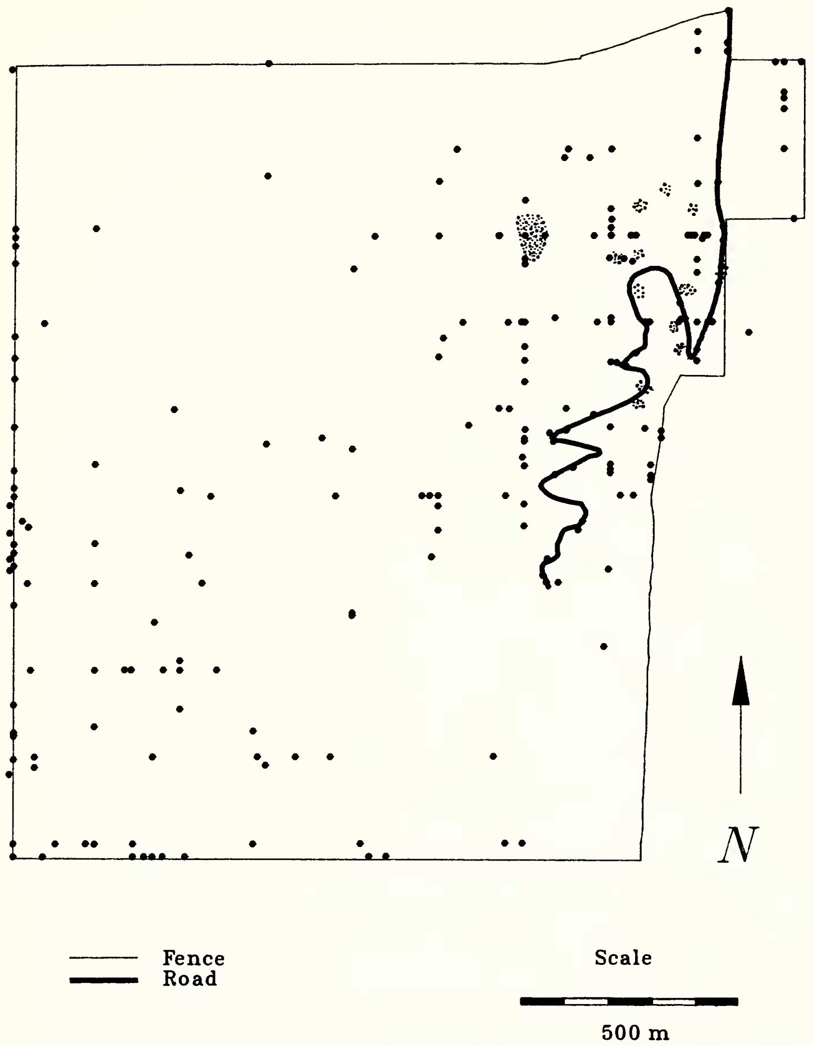

FIG. 3. Distribution of *Hordeum murinum* at Desert Laboratory in 1906 (stippled areas) and 1983 (dots). From Turner and Bowers (1988).

Why have these seven exotics been able to invade habitats that have undergone no appreciable disturbance for decades? We offer several mutually dependent explanations: favorable climate, prior evolution in regions with intensive pastoralism, the grazing history of southern Arizona, minimal integration into native food webs, and reproductive biology.

Climate. Exotics typically naturalize where climate and vegetation are similar to those of their source areas (Baker 1986). Biseasonal rainfall and subtropical temperatures make the northeastern Sonoran Desert vulnerable to two separate legacies of human landscape alteration: the "Mediterraneanization" of California (Heady 1977; Le Houerou in press) and the "Africanization" of the Neotropics (Baker 1978; Parsons 1970).

The six naturalized annuals on our grounds are native to the Mediterranean region and the Near East, where they grow in winter-rainy climates. *Bromus rubens* ranges from Asia Minor through the Mediterranean region (Tsvelev 1983), where it occurs in natural steppe vegetation and cultivated fields (Feinbrun-Dothan 1986; Hubl and Holzner 1982; Ayyad and Ammar 1974). Since its introduction in the mid-1880's, the species has spread from California to Texas and south into Baja California (Correll and Johnston 1970; Gould and Moran 1981). Its virtual absence from the Great Basin is probably related to sensitivity to frost (Hulbert 1955). *Schismus barbatus* and *S. arabicus,* both highly successful invaders in the Mojave and Sonoran deserts, grow in a variety of arid and semi-arid vegetation types as well as in disturbed sites from the Mediterranean through the Near East (Conert and Turpe 1974; Feinbrun-Dothan 1986). *Hordeum murinum* typically grows in disturbed, ruderal sites (Davison 1971; Frenkel 1977; Zohary 1973) or cultivated fields (Tadros and Atta 1959; Zohary 1950). It does not often dominate in stands of perennial vegetation in its native Eurasia, but it can be a common component of annual pastures elsewhere, as in Australia (Rossiter 1966) and California (Heady 1977; Jackson 1985). *Erodium cicutarium* can be found in disturbed or open habitats over most of Eurasia (Webb and Chater 1968; Vvedenskii 1974; Zohary 1972). It was among the earlier invaders in California (Heady 1977; Wester 1981). Various forms in the *Sisymbrium irio* complex can be found from Europe to India (Khoshoo 1955, Titz 1969). The species spread from southern to northern Europe during the seventeenth through nineteenth centuries (Ball 1964; Ellenberg 1988; Salisbury 1964), more or less concurrently with its colonization of North America.

The Africanization of our study site is evident in the establishment of the introduced perennial grass *Pennisetum ciliare,* which is native from northwestern India through the Middle East to southern Africa (DeLisle 1963). Coming from an area where climates are subhumid to arid with predominantly warm-season rainfall, *P. ciliare* is well adapted to exploit soil-moisture regimes typical of the summer and fall in southern Arizona (Cox et al. 1988). Although present on our study area since at least 1968, this species did not become extensively naturalized until the 1980's, after two periods of unusually wet summers. During the first of these, from 1970 to 1972, warm-season (October–May) rainfall exceeded the average (186 mm) by 103, 128 and 119 mm, respectively. During the second, from 1982 to 1984, warm-season totals were 134, 200 and 116 mm, respectively, above the average. Undoubtedly the more recent wet interlude and perhaps also the earlier one contributed to the increase of *P. ciliare.* Climatic fluctuations may also promote invasions by causing mortality of established natives, thereby creating openings for establishment (Tisdale et al. 1965). On slopes where *P. ciliare* has been invading, there has been considerable mortality of *Encelia farinosa,* apparently caused by freezing.

Evolution with pastoralism. The pattern of invasions between arid habitats in the Old and New worlds is not symmetrical. New World annuals and grasses have not become widely established outside of ruderal sites in either North Africa (Le Floc'h et al. 1990, Le Houerou in press) or southern Africa (Brown and Gubb 1986). Highly disturbed ruderal and segetal conditions developed earlier and more extensively in the Old World (Diamond 1988). While the emerging symbiosis among humans, large domestic animals and crops subjected Old World floras to selection under increasing disturbance (Jackson 1985; Naveh 1967; Young et al. 1972), Holocene vegetation in North America developed with a significantly reduced megafauna (Martin and Klein 1984) and no pastoralist societies. These contrasting histories resulted in the Sonoran Desert having relatively few species adapted to intensive grazing in comparison with floras from similar climates in the Old World.

Grazing history. There are strong connections between invasions of exotic plants and the advent of widespread pastoralism in the Sonoran Desert. The pattern of overgrazing on Arizona rangelands around the turn of the century has been well-documented (Wagoner 1952; Bahere and Bradbury 1978). The drought of 1890–1892, one of the worst on record for Arizona, aggravated the effects of overgrazing (Bahre and Bradbury 1978). By 1910, the desert grassland had been denuded of perennial grasses, and native annuals such as *Aristida adscensionis* and *Bouteloua aristidoides* had replaced them (Griffiths 1910).

Exotic annuals also increased as perennial grasses declined. *Erodium cicutarium* appeared in the San Pedro Valley east of Tucson by 1880 (Arizona Daily Star, February 10, 1880) and in the Sulphur Springs Valley by 1866 (Thornber 1906). By 1903 this species was locally naturalized on overgrazed ranges south of Tucson (Thornber 1903), and by 1910, *Hordeum murinum* was also becoming established on ranges in the vicinity (Thornber 1910). Range managers deliberately introduced certain exotic species. *Bromus rubens* was one of 24 annual forage species sown on the Santa Rita Experimental Range south of Tucson in the winters of 1906–1907 and 1907–1908 (Thornber 1910). *Eordium cicutarium* was also sown by at least one rancher (Arizona Daily Star, June 13, 1880).

The timing of these events strongly suggests that overgrazing fostered establishment of exotic annuals on southern Arizona ranges. A similar process has been implicated in California, where decades of overgrazing removed the native cover, leaving the land vulnerable to colonization of exotics (Biswell 1956; Naveh 1967; Frenkel 1977; Wester 1981). Although we have no quantitative evidence regarding the history of livestock on the Desert Laboratory grounds, it is likely that grazing before 1907 favored the establishment of exotics in the vicinity.

This is not to say that disturbance by pastoralism is the sole cause of invasions. McKell et al. (1962) suggested that communities of annual plants—such as those in the deserts of California—are "extraordinarily open." In 1986, after a drier than normal winter, we first detected *Schismus* sp. and *Brassica tournefortii* on the floor of MacDougal Crater in northwestern Sonora, Mexico. The crater is inaccessible to domestic livestock, and anthropogenic disturbance has been limited to occasional visits by botanists and others. This and similar examples suggest that Sonoran Desert communities are relatively open to invasion by Old World exotics. Such "openness" may result from a combination of factors, among them an initial lack of integration into food webs, the reproductive biology of invading species and competitive effects.

Integration into food webs. An invading species, particularly one from another continent, is unlikely to meet resident pathogens or predators adapted to exploit it intensively. Exotic plant species may profit from a period free of such biotic checks as diseases and insects, as noted by McKell et al. (1962) for the grass *Taeniatherum asperum* (Simonaki) Nevskii. Even highly palatable invaders may be 'hidden' when outnumbered by other species (Risch and Carroll 1986). Once an invading plant increases, evolutionary and behavioral responses of consumers and pathogens begin to integrate it into the food web, and its initial advantage declines. Seeds of *Erodium cicutarium,* for example, are heavily used by native granivores (Inouye et al. 1980; Soholt 1973; Stamp and Ohmart 1978; De Vita 1979). Herbivore effects are not always negative, however; in many cases, native consumers are effective dispersal agents (Knight 1986; Rissing 1986).

Reproductive biology. With the possible exception of *Sisymbrium irio,* the naturalized exotics on our study site are apparently self-compatible or apomictic (Booth and Richards 1976; DeGroote and Sherwood 1984; Faruqi and Quraish 1979; Martin and Harding 1982; Wu and Jain 1978), conforming with Baker's (1955) observations on successful weeds.

Most native annuals studied to date show relatively precise requirements for germination (Went 1948, 1949; Went and Westergaard 1949; Juhren et al. 1956; Tevis 1958), so that in a given year there are seldom enough temperature-moisture combinations to germinate all the species in the seed bank (Juhren et al. 1956). Many require a rainfall event of more than 25 mm to germinate (Beatley 1974). Germination requirements of the naturalized exotics appear to be less precise. Thus, in years unfavorable for germination of native annuals, such exotic species as *Bromus rubens, Sisymbrium irio* and *Schismus barbatus* still establish and reproduce in favorable microsites.

Some native annuals may have density-dependent germination (Inouye 1980) whereby the presence of established plants on a site prevents others from germinating. *Bromus rubens, Hordeum murinum* and *Schismus barbatus* do not suppress germination at high densities (Wu and Jain 1979; Szarek et al. 1982; Borchert and Jain 1978; Davison 1971). After good rains, mass germination in these species produces dense stands that suppress other ephemerals.

Seeds of *Erodium* and *Sisymbrium* can have extended dormancy (Roberts 1986; Wilson and Duff 1984). In contrast, *Schismus, Hordeum* and *Bromus* do not normally form long-lasting seed banks (Loria and Noy-Meir 1980; Popay 1981; Roberts 1981; Wu and Jain 1979). Populations build up rapidly during a series of good years, but a bad season can cause catastrophic losses. Following a poor year, seeds are dispersed into depleted areas from individuals that reproduced in more mesic sites.

In short, the lack of specificity in germination requirements, the ability to reproduce under intense crowding and marginal conditions, and effective seed dispersal are critical factors in the successful naturalization of certain exotics at the Desert Laboratory.

Competitive effects. Whether naturalized annuals are crowding native species out of the habitat is unknown. The native *Erodium texanum* is a common associate of *E. cicutarium* at the Desert Laboratory. Inouye et al. (1980) indicate possible competition between the two.

It appears that *Pennisetum ciliare* is displacing *Encelia farinosa* from some rocky slopes. The root systems of both exploit the upper soil horizons (Cannon 1911; Christie 1975), but some temporal partitioning of soil moisture should exist. *Pennisetum* is most active during the warm season whereas *Encelia* grows in late winter and spring. *Encelia* has not reestablished within larger stands of *Pennisetum.* Apparently a temporary competitive release can start a *P. ciliare* invasion (Danin 1976) which may be consolidated by allelopathic effects (Cheam 1984; Hussain et al. 1982).

Because *Pennisetum ciliare* tolerates burning better than most long-lived Sonoran Desert perennials (Mayeux and Hamilton 1983; Mott 1982; 't Mannetje et al. 1983), occasional fires may promote its increase at the expense of native species. *Bromus rubens* can produce substantial biomass, particularly during wet winters (Beatley 1969; Bowers 1987). The resulting dry litter seems to promote the spread of fires that restructure the perennial vegetation without adversely affecting *B. rubens* (Beatley 1966; Brown and Minnich 1986; Rogers and Steele 1980).

Conclusions

Though much of the Desert Laboratory grounds has been protected for decades, certain exotic plant species occur throughout the property on disturbed and undisturbed sites alike. Winter annuals from the Mediterranean and Near East predominate in the exotic flora, whereas introduced summer annuals play a minor role. The changes that have occurred over the last 50 to 75 years appear irreversible. Grazing before 1907 could have created conditions that favored the initial invasion by exotic annuals. Exotic perennial grasses were introduced later (Cox et al. 1988), and their invasion appears to be accelerating. The most successful exotics, whether annual or perennial, share features that indicate evolution in ruderal habitats in climates similar to that of the Sonoran Desert.

The character and rate of change in the Desert Laboratory flora have undoubtedly been influenced by its proximity to the rapidly growing city of Tucson, which has often served as a source of propagules. Parts of the Sonoran Desert remote from urban centers have not undergone the rapid proliferation of exotics seen at the Desert Laboratory; nevertheless, the invasion of relatively undisturbed habitats within the grounds indicates a possible future of Sonoran Desert vegetation.

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Appendix I.

Status and History of Selected Exotics at the Desert Laboratory, Tucson, Arizona

The vouchers cited below are deposited at ARIZ. It is difficult to determine when most of these introductions occurred. An exotic species may have been established on our study area many years before its initial documentation.

Avena fatua L. Scattered and rare; distrubed sites along roads and in washes. Established in California by 1824 (Frenkel 1977); present in Arizona by 1902 (*Thornber s.n.*); first Desert Laboratory collection made in 1983 (*Bowers and Turner 2222*).

Brassica tournefortii Gouan. Scattered and rare; fence lines and washes. Introduced into Arizona ca. 1960 (Mason 1960); first Desert Laboratory collection made in 1978 (*Turner 78-1*).

Bromus rubens L. Widespread and common. Established in California by 1848 (Frenkel 1977), though not naturalizing to any appreciable extent for another 45 years (Davidson 1907); present in Tucson by 1909 (Thornber 1909) and beginning to spread to nearby "mesas" by 1910 (Thornber 1910); first Desert Laboratory collection made in 1968 (*Mason and Turner 68-130*). Perhaps introduced into Tucson area when sown as potential annual forage plant on Santa Rita Experimental Range in winter of 1906–1907 and 1907–1908 (Thornber 1910).

Bromus catharticus Vahl. Scattered and occasional; disturbed sites, often in low-lying areas. Present in Arizona by 1894 (Britton and Kearney 1894); first Desert Laboratory collection made in 1968 (*Mason and Turner 68-131*).

Caesalpinia gilliesii (Hook.) Wall. Local and rare. Wash borders near the west boundary and riparian thickets where floodwaters pond. First Desert Laboratory collection made in 1989 (*Burgess 7611*).

Centaurea melitensis L. Confined to landfill, where occasional. Established in California by 1824 (Frenkel 1977); present in Arizona by 1897 (Toumey 1897); first noted at Desert Laboratory in 1983.

Chenopodium murale L. Scattered and occasional; disturbed sites, often along fence lines. Established in California by 1824 (Frenkel 1977); present in Arizona by 1901 (*Thornber 4433*); not known from Desert Laboratory until 1983 (*Bowers 2587*).

Cynodon dactylon L. Scattered and locally abundant; disturbed, low-lying areas. Established in California by 1860 (Frenkel 1977); growing without cultivation in Arizona by 1891 (*Toumey s.n.*); known from Desert Laboratory Hill since 1909 (Spalding 1909).

Dimorphotheca sinuata DC. Scattered and rare; usually along washes. Cultivated in Arizona since the 1940's, naturalized in various locations by the 1970's (Earle 1973); first Desert Laboratory collection made in 1978 (*Turner and Goldberg 78-8*).

Eragrostis lehmanniana Nees. Local and common; usually on disturbed sites but occasionally elsewhere. Introduced at Tucson in 1934 by the Soil Conservation Service (Flory and Marshall 1942); well established along roadsides in Tucson by 1946 (Gould 1946); first Desert Laboratory collection made in 1983 (*Bowers 2703*).

Erodium cicutarium (L.) L'Her. Widespread and common. Established in California by 1824 (Frenkel 1977); present in Arizona by 1866, no doubt introduced into the state by sheep from California (Thornber 1906) and also sown deliberately by at least one rancher (Arizona Daily Star, June 13, 1880); known from the San Pedro Valley since 1880 (Arizona Daily Star, February 10, 1880), the Tucson area since 1903 (Thornber 1903) and from Desert Laboratory since 1906 (Spalding 1909).

Hordeum murinum L. subsp. *glaucum* (Steud.) Tzvelev. Widespread and occasional. Established in California by 1824 (Frenkel 1977); present in Arizona by 1894 (Britton and Kearney 1894); established in the Salt River valley by 1897 (Toumey 1897) and a noxious weed there by 1901 (McClatchie 1901); known from Desert Laboratory since 1906 (Spalding 1909); uncommon in the Tucson area until at least 1910 (Thornber 1910). Three major taxa have been defined in the *Hordeum murinum* group. On the basis of anther length, both *H. murinum* subsp. *leporinum* and *H. murinum* subsp. *glaucum* have been collected on the Desert Laboratory grounds. Lodicules are considered a more reliable diagnostic character (Baum and Bailey 1984a, b), and in this feature our collections conform to *H. murinum* subsp. *glaucum*.

Lactuca serriola L. Scattered and rare; disturbed sites, most often in washes. Established in California by 1860 (Frenkel 1977); present in Arizona by 1905 (*Thornber 5572*); first noted on Desert Laboratory grounds in 1983.

Lantana horrida H.B.K. Scattered and rare. An ornamental commonly cultivated in and around Tucson; first Desert Laboratory collection made in 1983 (*Bowers 2704*).

Lepidium oblongum Small. Local, occasional to common. Introduced into Arizona by 1902 (*Thornber s.n.*); first Desert Laboratory collection made in 1983 (*Bowers and Turner 2225*).

Malva parviflora L. Scattered and rare; low-lying disturbed sites. Established in California by 1824 (Frenkel 1977); present in Tucson by 1891 (*Toumey s.n.*); first Desert Laboratory collection made in 1978 (*Turner 78-5*).

Matthiola longipetala (Vent.) DC. ssp. *bicornis* Sibth. & Sm. Scattered and rare; on landfill and fence lines. Introduced into Tucson ca. 1905 and escaping from cultivation (Thornber 1909); first Desert Laboratory collection made in 1983 (*Turner and Goldberg 78-13*).

Melia azederach L. Local and rare on landfill. Common ornamental in and around Tucson; first Desert Laboratory collection made in 1983 (*Turner 83-4*).

Melilotus indicus (L.) All. Local and rare; moist sites near ponds. Established in California by 1848 (Frenkel 1977); present in Arizona by 1891 (*Toumey s.n.*); common weed in southern Arizona by 1900 (McClatchie 1900); first Desert Laboratory collection made in 1983 (*Bowers and Turner 2210*).

Molucella laevis L. Scattered and rare; usually in moist sites. An ornamental commonly cultivated in and around Tucson; first Desert Laboratory collection made in 1979 (*Turner and VanHylckama 79-64*).

Nicotiana glauca Grah. Scattered and rare; usually in moist sites, but also on steep slopes with southerly aspects. Established in California by 1848 (Frenkel 1977); cultivated in Tucson by 1891 and escaping from cultivation by 1904 (*Thornber 480*); first Desert Laboratory collection made in 1983 (*Turner 83-11*).

Opuntia microdasys (Lehm.) Pfeiffer. Local and rare; gravelly flats near the west boundary; first noted on Desert Laboratory grounds in 1984.

Parkinsonia aculeata L. Scattered and rare; most common on sanitary landfill. Cultivated in and around Tucson; first Desert Laboratory collection made in 1968 (*Warren and Turner 68-155*).

Pennisetum ciliare (L.) Link. Scattered, rare to abundant. Introduced to Arizona by Soil Conservation Service ca. 1938, spreading from plantings by 1954 (Kearney 1954); first Desert Laboratory collection made in 1968 (*Warren and Turner 68-11*).

Pennisetum setaceum (Forsk.) Chiov. Local and occasional. Usually in disturbed sites where runoff collects, also in crevices of some basalt outcrops; first Desert Laboratory collection made in 1983 (*Bowers 2754*).

Phacelia campanularia Gray. Local and rare; not established. A California native, doubtless spreading to our area from nearby plantings; first Desert Laboratory collection made in 1983 (*Bowers and Turner 2226*).

Phalaris minor Retz. Local and occasional; moist sites. Introduced into California by 1882 (Robbins 1940); present in Arizona by 1913 (*Thornber s.n.*); first Desert Laboratory collection made in 1978 (*Turner and Goldberg 78-18*).

Polypogon monspeliensis (L.) Desf. Local and occasional; moist sites. Established in California by 1848 (Frenkel 1977); present in Arizona by 1891 (*Toumey s.n.*); first Desert Laboratory collection made in 1978 (*Turner and Goldberg 78-20*).

Rhus lancea L. Local and rare; moist areas along washes. Introduced into California in 1919; first planted in Tucson in 1928 (Schmidt 1969); first Desert Laboratory collection made in 1984 (*Bowers 2970*).

Salsola australis R. Brown. Scattered and common; abundant on landfill. Introduced into U.S. in 1886 in flax seed sown in South Dakota and established in California by 1895 (Robbins 1940); first collected in Tucson in 1892 (*Toumey s.n.*). Oddly, in 1897 Toumey wrote, "There is no direct evidence that this weed had yet found its way into Arizona," and in 1904, Griffiths described *Salsola* as common along railway lines in northern Arizona but added, "so far as known it does not occur in the southern part of Arizona at all." In any case by 1913, *Salsola* was apparently well established in Tucson (*Thornber 7305, Thornber s.n.*). The first Desert Laboratory collection was made in 1968 (*Warren and Turner 68-160*).

Schismus arabicus Nees. Widespread, common to abundant. Present in Arizona by 1933 (*Peebles 9098*); first Desert Laboratory collection made in 1968 (*Mason and Turner 68-128*).

Schismus barbatus (L.) Thell. Widespread, common to abundant. First collected in Arizona in 1926, naturalized in central part of state by 1931 (Kearney 1931) and in southern part by 1949 (Gould 1949); first Desert laboratory collection made in 1983 (*Bowers 2455*). Apparently not introduced into California until 1935 (Robbins 1940). It is unclear whether *S. arabicus* and *S. barbatus* both occur in our study area. Faruqi and Quaraish (1979) and Faruqi (1981) found that in Libya, intermediate forms apparently derived from hybridization and backcrossing between the two taxa have been stabilized by high rates of autogamy. They concluded that there is no justification for regarding *S. barbatus* and *S. arabicus* as separate species. Specimens from the Desert Laboratory fit *S. barbatus* as defined by Conert and Turpe (1974). A review of the North American material seems in order.

Sisymbrium irio L. Widespread and occasional. Present in Arizona by 1909 (*Thornber s.n.*), in California by 1918 (Robbins 1940); abundant in the Phoenix area by 1933 (Hamilton 1933); first Desert Laboratory collection made in 1968 (*Warren and Turner 68-47*).

Sisymbrium orientale L. Scattered and occasional; along washes. Present in Arizona by 1931 (*Harrison et al. 7554*); first Desert Laboratory collection made in 1978 (*Turner and Goldberg 78-11*).

Sonchus oleraceus L. Scattered and rare; often along washes. Established in California by 1824 (Frenkel 1977); present in Tucson by 1897 (Toumey 1897); first Desert Laboratory collection made in 1983 (*Bowers 2502*).

Tamarix ramosissima Ledeb. Occasional at ponds in clay quarries. First collected in Arizona in 1901 (Horton 1964); first Desert Laboratory collection made in 1968 (*Warren and Turner 68-120*). A cultivated species that has become widely naturalized in the Southwest.